Breakout session #1:

Quantifying the benefits and challenges of HYPERSEPCTRAL remote sensing

Looking towards the future of space-borne radiometry

Co-chairs: Ryan Vandermeulen, Kevin Turpie, Astrid Bracher, Susanne Craig, Emmanuel Boss, Cecile Rousseaux

Hyperspectral Remote Sensing in three acts:

DN

SENSOR — *Sensor design considerations (SNR, spatial/spectral/temporal), calibration, rad. performance.*

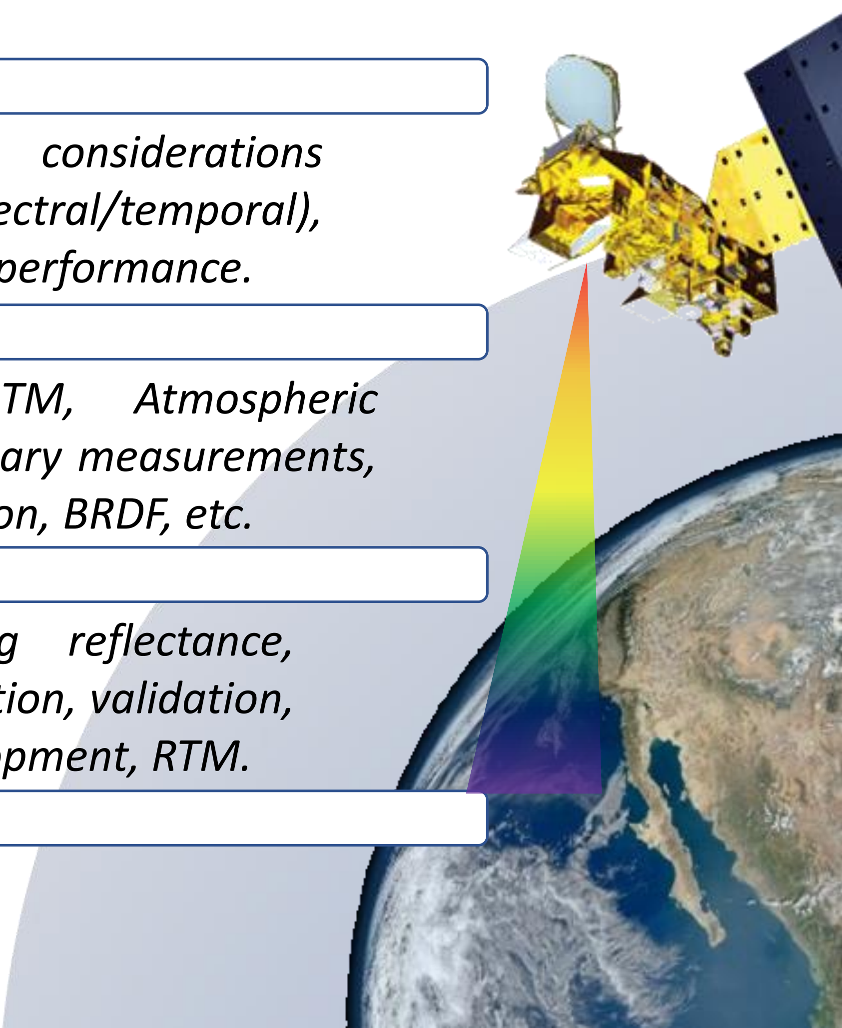
TOA Radiance

ATMOSPHERE — *Atmospheric RTM, Atmospheric correction, ancillary measurements, Aerosol absorption, BRDF, etc.*

Aerosols, etc.

OCEAN — *Remote Sensing reflectance, vicarious calibration, validation, algorithm development, RTM.*

Rrs, products, etc.



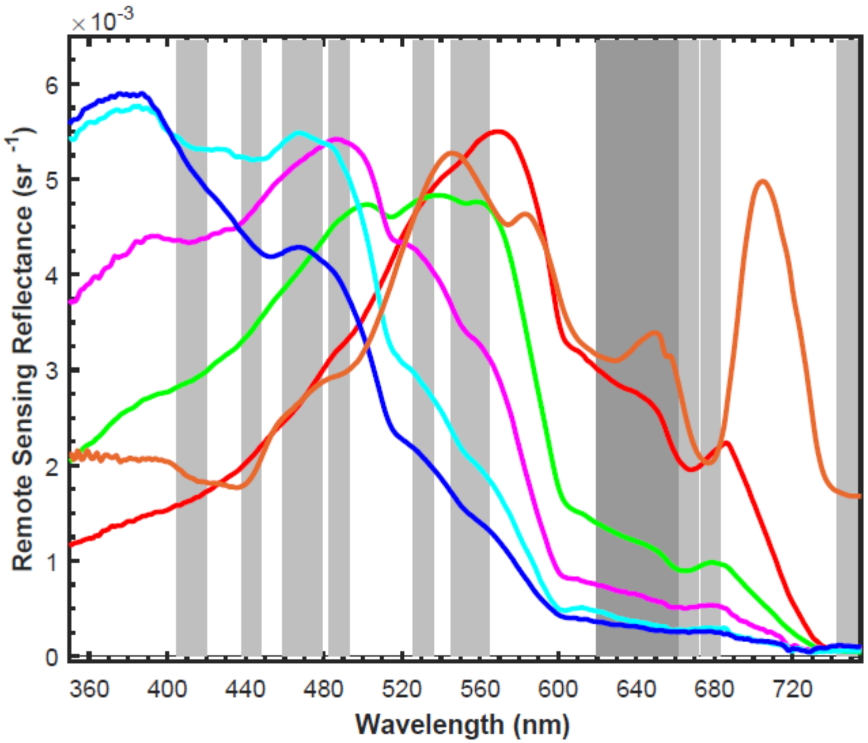
14:15 – 14:23	**Introduction and Meeting Objectives** *Susanne Craig (Dalhousie Univ.)*
PART 1: Products, Science Questions and Applications (50 minutes)	
14:25 – 14:33	**Scientific Roadmap for Phytoplankton Diversity from Ocean Color** Astrid Bracher (AWI)
14:35 – 14:43	**Out-of-the-Box Applications Derived from Hyperspectral Remote Sensing** Heidi Dierssen (UCONN)
14:45 – 15:10	**Open Discussion**
PART 2: Atmospheric Correction Challenges (50 minutes)	
15:10 – 15:18	**New approaches to Atmospheric Correction** Francois Steinmetz (HYGEOS)
15:20 – 15:28	**Atmospheric correction of HICO data** Amir Ibrahim (NASA/USRA)
15:30 – 15:55	**Open Discussion**
PART 3: Sensor Design Considerations (50 minutes)	
15:55 – 16:13	**CEOS feasibility study for a hyperspectral sensor to observe coastal and inland aquatic ecosystems** Arnold Dekker (CSIRO)
16:15 – 16:40	**Open Discussion**
Summary and Connections (10 – 15 minutes)	
16:40 – 17:00	**Final discussion** – Breakout session synthesis and community input

- 6 talks outlining state of the art advances in the field of ocean color remote sensing
- ~100 minutes worth of discussion on pressing issues to the community:

ACT 1:
Algorithms, products and applications

Our remote sensing community is moving towards hyperspectral data for good reason:

- Phytoplankton diversity (5 nm)
- Aerosol absorption
- Bottom reflectance
- Inherent optical properties
- Water Quality / HABs
- Coral bleaching, sea ice, microplastics, floating vegetation, “enslaved” chloroplasts
- Beyond “products,” each improvement opens up new science questions and process studies…



ACT 1:
Algorithms, products and applications

- ~~WHAT CAN WE DO WITH HYPERSPECTRAL MEASUREMENTS?~~
- *What are our knowledge gaps*
- *What do you need to mitigate them?*

We want to hit the ground running when we roll out the next generation of hyperspectral satellite missions…

Hyperspectral isn't just multispectral with more bands, and we need to get out of this mindset…

Challenges with hyperspectral data "products":

- From a management perspective, making end user requirements based on data findings is difficult without regular products available – Catch 22.
- We have yet to **fully** catalogue what the lack of wavelengths and/or radiometric sensitivity prevents us from doing, metrics of performance.
- We haven't fully defined what "hyper" spectral is.
- Correlation among channels (redundancy) is often a factor of spectral bandwidth, there are smaller features that can be exploited.
- Volume of hyperspectral data can be quite formidable.

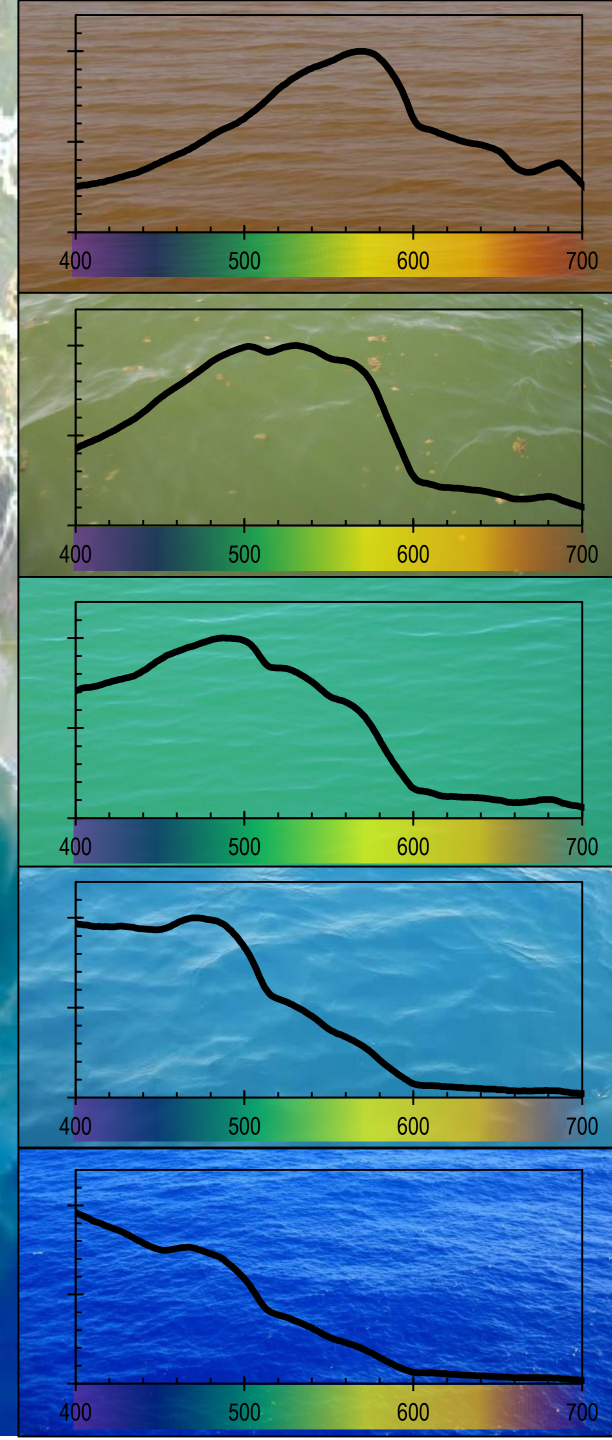
Looking forward →

- Regardless, one of the best arguments for hyperspectral is the flexibility and adaptability (Varying water types, shifting peaks, etc.)
- Establish framework for clear **traceability of algorithm errors** by improving in-situ data for full description of hyperspectral a & bb and phytoplankton diversity
- Exploit already current hyperspectral satellite data for application of specific (e.g. PFT) retrievals
- Could benefit from extensive spectral library to support algorithm development.

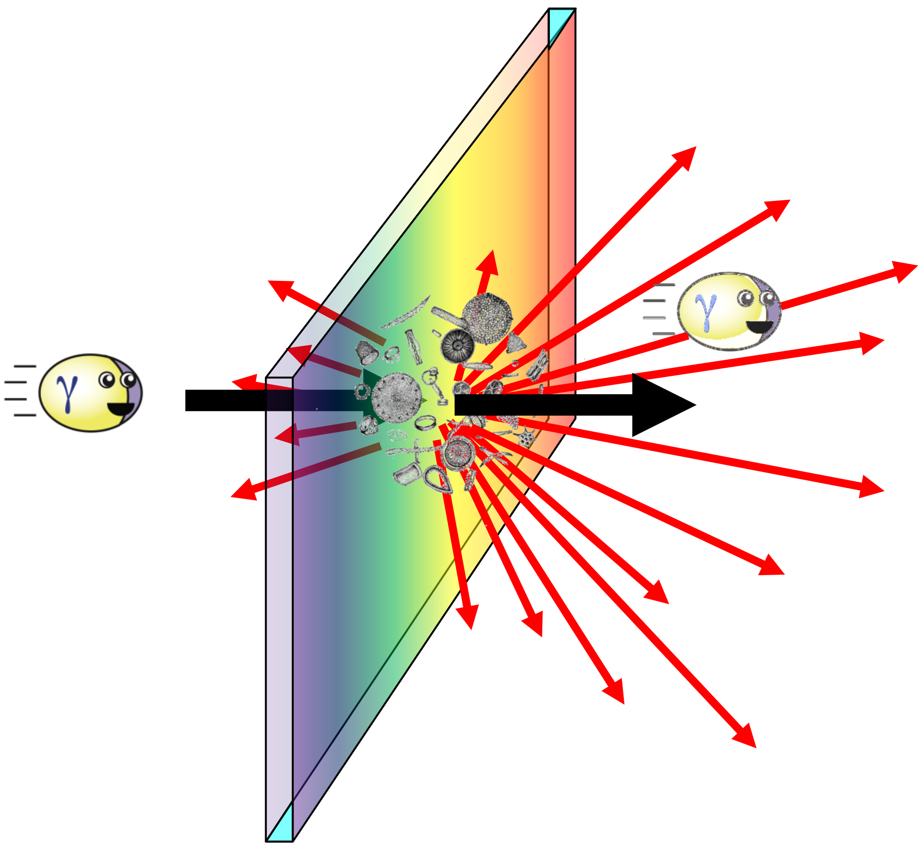
Looking towards the future

Need development of hyperspectral in situ instruments:

- ***Hyperspectral b_b!***
- ***Bio-optical instruments robust to turbid waters***
- ***Global network of hyperspectral validation platforms…***



Can RTM be improved from hyperspectral data, and vice versa?



- Can we possibly afford the opportunity to abandon reliance on empirices with increased spectral bands?
- Still limited in terms of hyperspectral parameterization
- Need to better characterize noise inherent in instruments to include in RT modeling → better closure.

Scientific roadmap for long time series PFT data from OC

Bracher & 20 more PFT-experts worldwide (2017) Frontier in Marine Science 4: 55

Gap	Status	Medium-term action	Long-term action
Satellite Sensors	Multispectral sensors with limited PFT information Limited exploitation of hyperspectral: - SCIAMACHY PFT data but low coverage/resolution - AC failed to derive hyper-spectral Lw, RRS data (HICO)	Develop AC for hyper-spectral sensors Adapt hyperspectral PFT algorithms to current hyperspectral satellite data Develop synergistic hyper& multispectral PFT products	Exploit adding bands to multispectral (OLCI,…) Merge all sensors' PFT da-ta for long term coverage Launch hyperspectral OC sensors (PACE, …)
Uncer-tainties	Deficient theoretical background for inversions? RTM lack PFT-info (esp. b_b) No appropriate in-situ HPLC-not really PFT, other PFT data require integration Spectral IOPs (esp. bb) limited	Optimize inversion (RTM) Round-Robins: PFT data format, method & QC Exploit all *in-situ* PFT, auton. techniques, hyper AOP&IOP Use complementary data to constrain algorithms	**Framework for clear traceability of errors** Curate existing data sets Ensure complete PFT, hyperspectral IOP & AOP acquisition

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ACT 2: The Atmospheric correction problem:

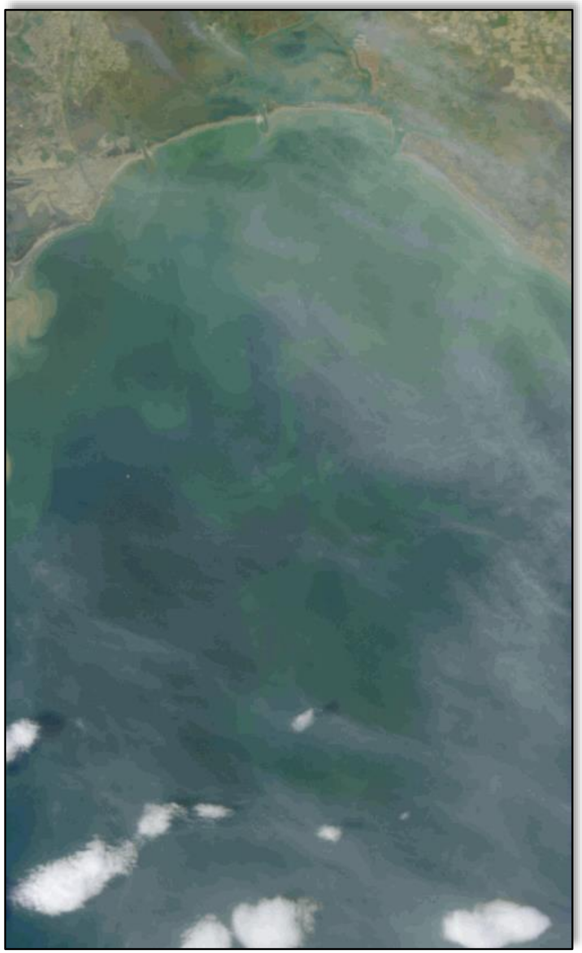
Discussed two major approaches:

- Using two parameters for ocean and three for atmosphere, to simultaneously retrieve TOA and ocean parameters through iteration (POLYMER).
- Two-band NIR correction applied to hyperspectral data
- Both can potentially be improved with hyperspectral information on NO_2, O_3, oxygen bands, water vapor, etc.

DISCUSSION:
Atmospheric correction

The atmospheric problem is a big one, and we don't have it that well constrained:

- PROBLEM: with perfect radiometric performance and advanced algorithms, "false" absorption peaks can confound results.
- Spectral resolution of sensor data may not be sufficient to correct for peaks, inelastic scattering (Raman).
- High sensor/solar zenith angles means we are missing millions of km^2
- Solutions?
  - Vicariously calibrate the errors away?
  - Subsampling for absorbing gas correction?
  - Improve BRDF with hyperspectral data to move beyond Case1 chlorophyll assumptions?
  - Fit ocean and atmosphere at the same time (e.g. Polymer)
  - Improve coupled ocean atmosphere RTM for high solar zenith angles
  - Include polarization measurements to improve AC…



DISCUSSION:
UV hyperspectral capabilities

What hyperspectral products into the UV should atmospheric correction scientists be aware of?

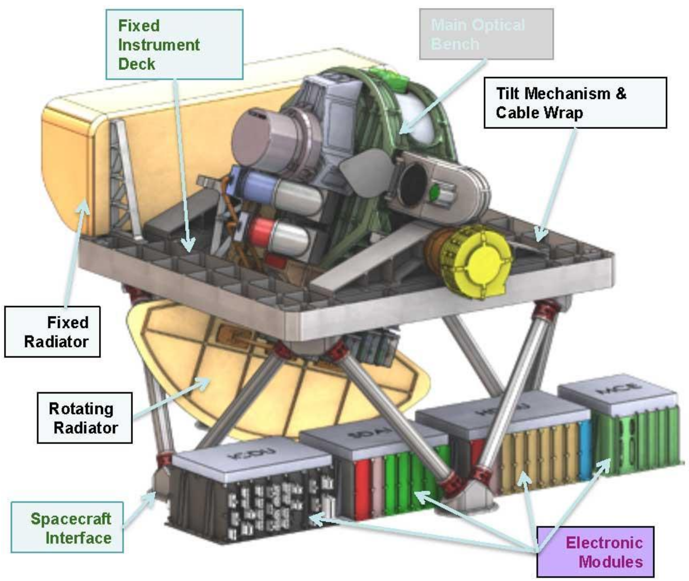
<u>THE GOOD:</u>

- Nitrogen dioxide (NO_2) absorption peak, big for coastal polluted cities
- 2^{nd} band to constrain your atmospheric correction (- UV)
- Mycosporine-like amino acids (MAA) absorb into the UV, could help distinguish PFTs, RT simulations could help unravel
- Better CDOM retrieval and separation of marine versus terrestrial

<u>THE BAD:</u>

- High uncertainty in solar irradiance in UV, and our calibration sources are weak.

ACT 3: Sensor design considerations



Preliminary draft diagrammatic representation of the PACE Ocean Color Instrument (OCI)

The sensor design problem:

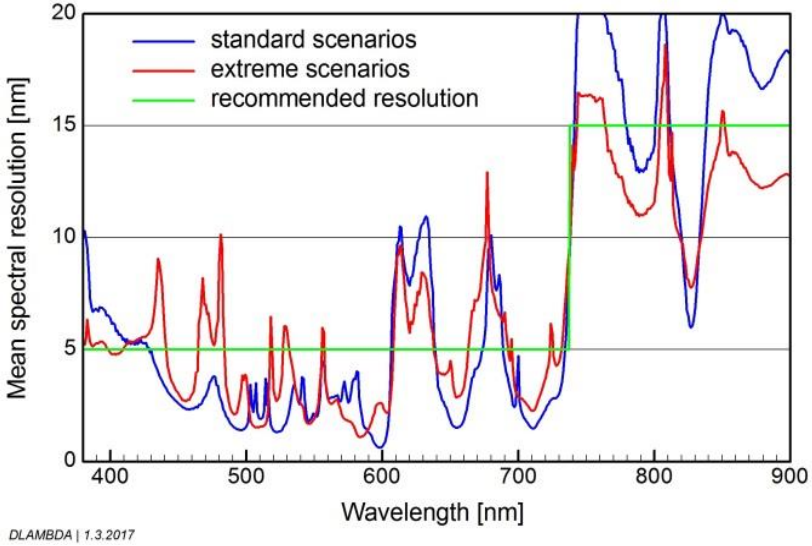
The perpetual balance between spectral, spatial, temporal, and radiometric performance is not an easy line to tow.

Scope of the Feasibility Study
Imaging Spectrometer for (non-Ocean) Aquatic Ecosystems

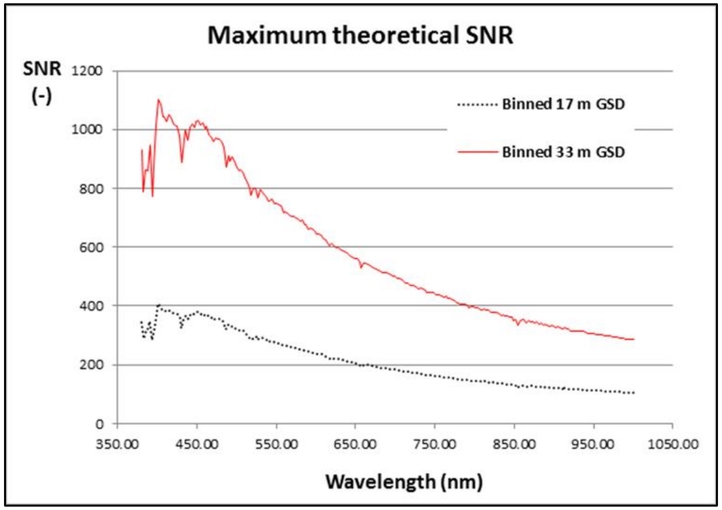
Presented by A.G. Dekker

- The CEOS response to (GEOSS) Water Strategy recommendations was endorsed by CEOS at the 2015 CEOS Plenary.
- This study addresses a feasibility assessment to determine the benefits and technological difficulties of designing a hyperspectral satellite mission focused on water quality measurements.
- Focused on inland, near coastal waters, benthic, shallow water bathymetry applications. NOT SO SIMPLE
- Focus is on a global mapping mission

Spectral resolution and SNR suggestions for *coastal* waters



The recommended spectral resolution of a hyperspectral sensor based on these simulations is 5 nm (+/- 3 nm) from 380 to 737 nm, and 15 nm from 737 to 900 nm.



A simulation of achievable radiometric resolution within constraints of spectral and spatial resolution in terms of SNR (By M. Bergeron CSA)

Trade-off between spatial, spectral and radiometric resolution

DISCLAIMER: FOMULATED FOR COASTAL WATERS

The priority in specifications for an aquatic ecosystem imaging spectrometer (or many multi-bands sensor) is from 1 to 4:

1. Spatial resolution (as not getting a pure aquatic pixel avoids any measurement at all)
2. Spectral resolution (to discriminate between all the variables)
3. Radiometric resolution: should be as high as possible given priorities 1 and 2
4. Temporal resolution (varies from once a season to hourly intervals) can be solved by LEO+GEO and /or constellations of LEO's

- Depending on question, one seasonal image (if lucky) imparts its own bias. However, for extremely under-sampled region, even one seasonal image is huge advance.

DISCUSSION:
Sensor design considerations

- We lose a lot by leaving out IR/SST (Sentinal-2), temp. is large forcer in aquatic systems → should be sampled at similar spatial resolution.
- Hyperspectral lunar calibration capabilities are pertinent for hyperspectral mission.
- Feasibly, we can work towards the ultimate (spatial, temporal, spectral, and radiometric) sensor, but we need to make the case:
  - End user requirements are not mature
  - Managers want *validity* not accuracy.
  - But, to some degree there is a pure science element to EXPLORING hyperspectral data, we NEED to invest in the science in order to understand what hyperspectral can do…

SUMMARY:
Where do we go from here?

- Atmospheric correction is a HUGE issue, and it is the problem of the ocean color community, we need to resolve this issue.
- OC scientists need to engage with atmospheric scientists more, they are enthusiastic to help in our plight!
- We may require varying AC for varying spectral regions, new ‘recipes’ for high SZA regions.
- Decision tree approach for different regions instead of full inversions.
- One size hits all may not be a feasible model, but this can depend on your question. Continuity is a very important component of maintaining climate records…

SUMMARY:
Where do we go from here?

- Era of ‘big data’ or ‘The Fourth Paradigm’
- Currently we are not certain how hyperspectral will improve our knowledge about the ocean, but this is ok. Need more sophisticated approaches to fully exploit hyperspectral & other contextual Earth system data. We haven’t fully explored those tools and we need them!
- Big data, machine learning, neural networks, data mining, whatever your flavor, it is the new focus of Copernicus/ESA.